CoRe-H_2O – A Dual Frequency SAR Mission for Snow and Ice Observations

CoReH_2O - *COld REgion Hydrology High resolution Observatory*

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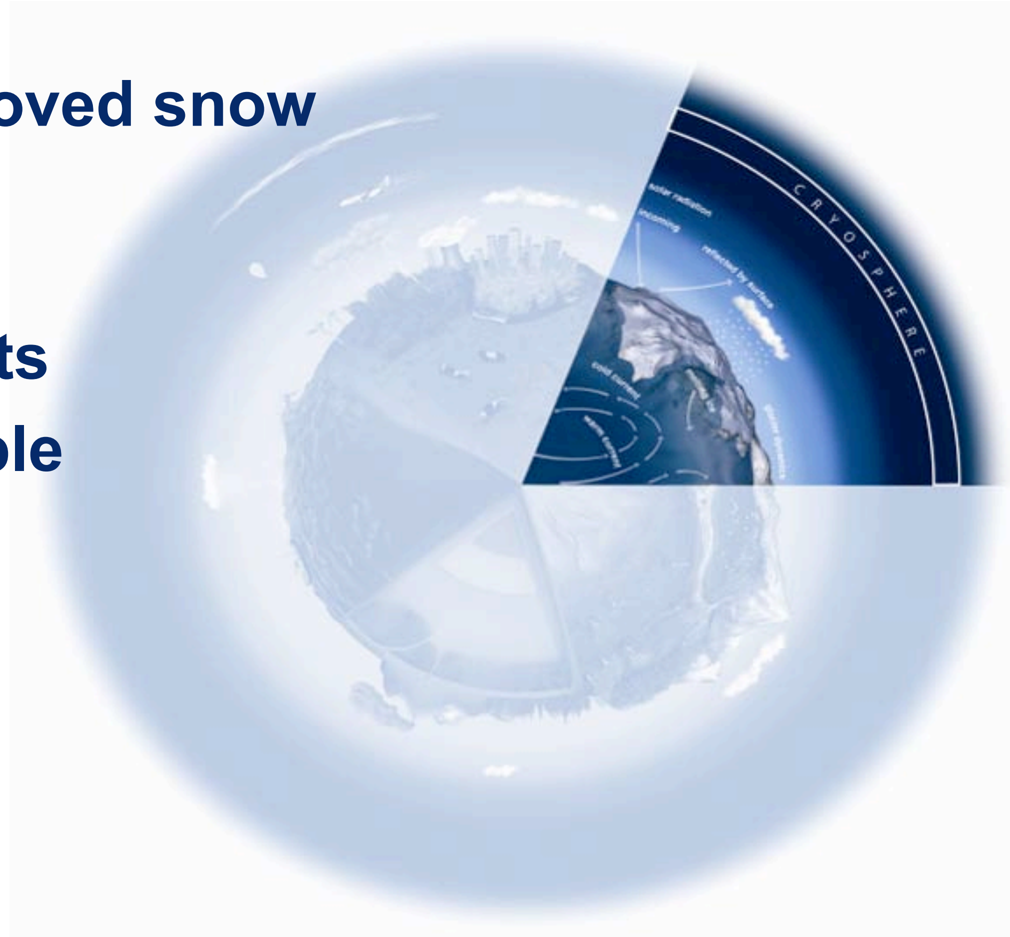
Outline of the Presentation



- Scientific Needs for improved snow and observations
- Mission Objectives
- Observation Requirements
- The Measurement Principle
- Retrieval methods
- Instrument Parameters
- Sensor and Payload
- The Next Step

The Need for Improved Snow and Ice Observations

Global climate system

- **Snow and ice are key elements of the climate systems, not properly represented in climate models. In particular *snow mass (SWE)* is poorly known.**

Hydrological and surface/atmosphere exchange processes

- **Snow cover shows high spatial heterogeneity. Spatially detailed data are needed for quantifying surface/ atmosphere exchange and the water cycle**

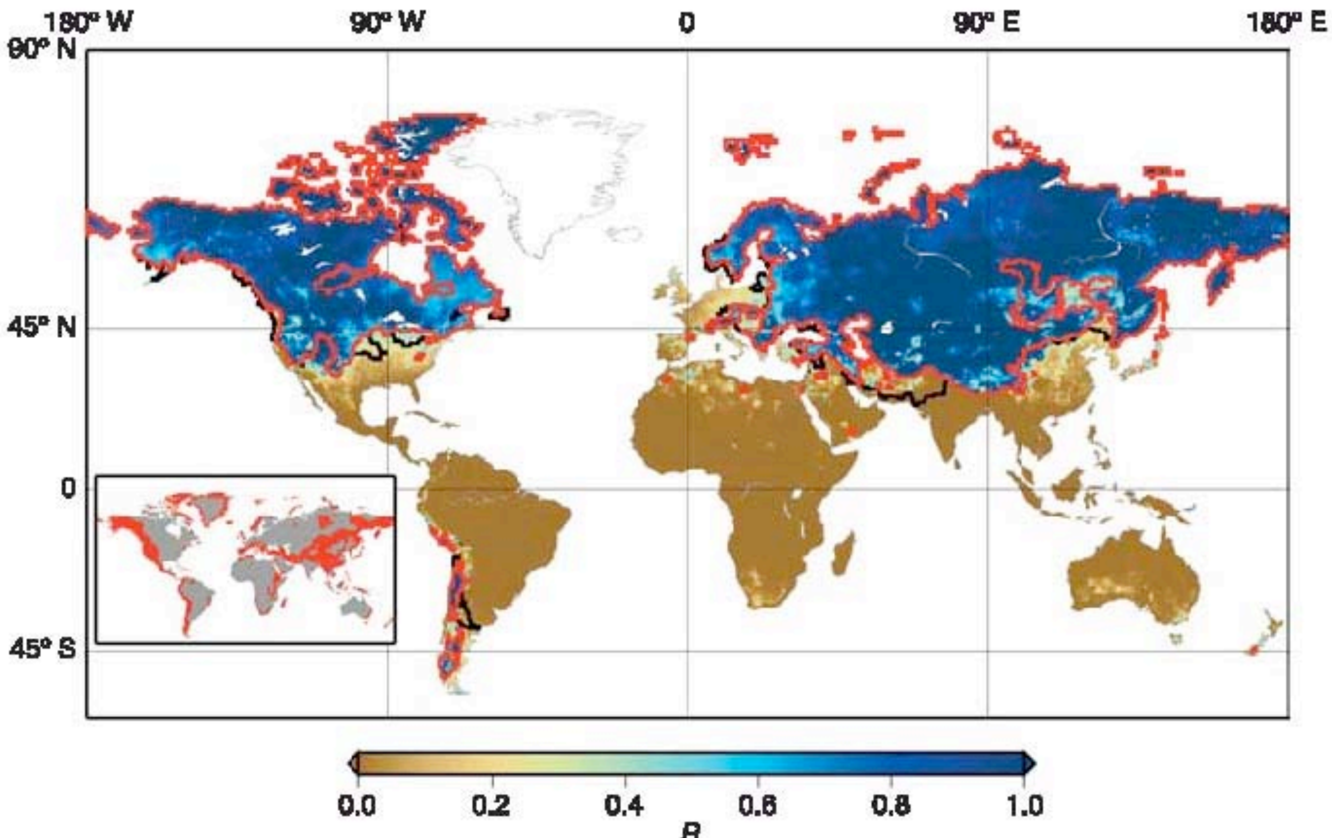
Glacier mass balance – climate interactions

- ***Glacier mass balance* is a key climate parameter, responding very sensitive to climate change – measured on very few glaciers world-wide**
- **Models with remote sensing input are needed to obtain the global view**

Snowmelt and glacier runoff - a crucial water resource

- **Snow cover and glacier retreat caused by climate change jeopardize the water supply to hundreds of millions of people.**
- **New models using spatially detailed snow observations are needed to improve water management and support measures to adapt to changes.**

Snow – A Vital Source of Water strongly affected by Climate Change



Accumulated annual snowfall divided by runoff   Barnett et al., *Nature*, 2005

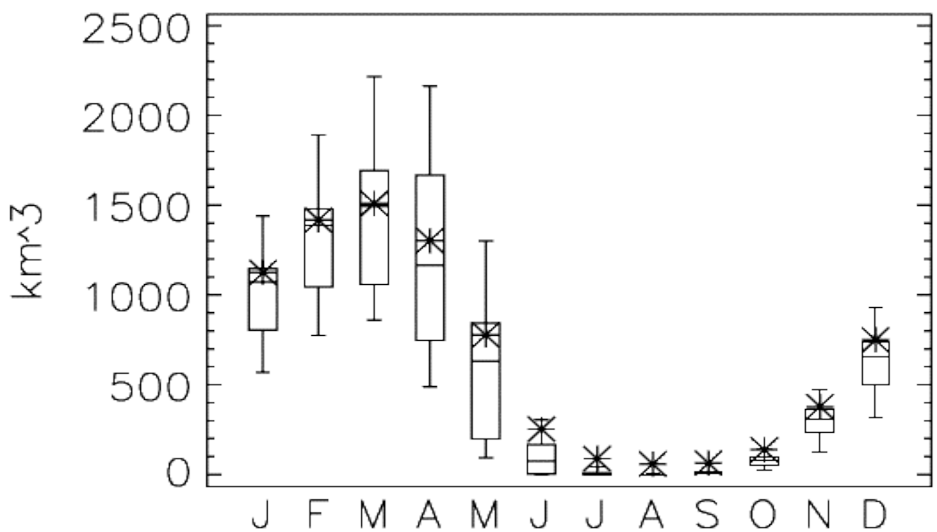
Snow and glacier melt dominates the water supply on many land areas.

Better data are needed to quantify the climate impact on water availability and enable early precautions for future shortages.

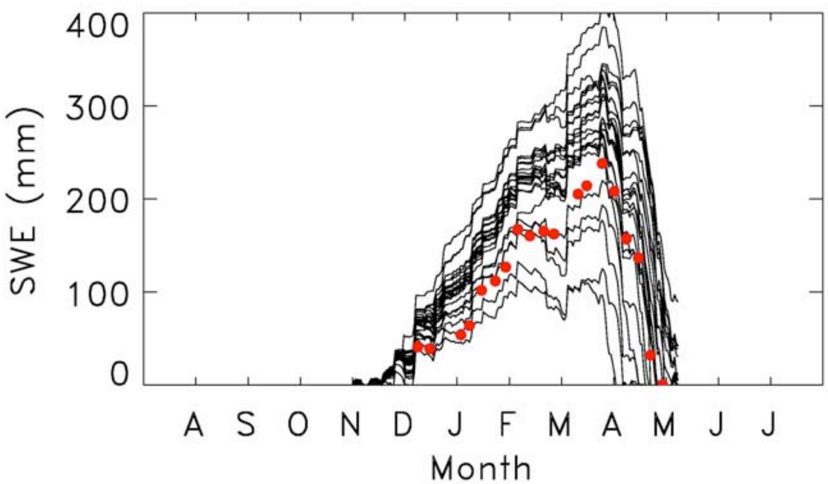
Snow mass (SWE) – poorly known from the local to the global scale

SWE observations are very sparse, and in many parts of the world completely missing

SWE computed by GCMs, LAMs and land surface processes models has large error bars



Total volume of snow-water storage (median and range) for North America by 18 different GCMs – intercomparison AMIP-2 (Frei et al., 2003)



Uncertainty in snow process modelling at local scale: Comparison of 23 point models for one snow station (Sleeper River, Vermont) (Etchevers et al., 2005)

Primary Mission Objective: Snow and Ice in the Water Cycle

- **Quantify the amount and variability of fresh water stored in terrestrial snow packs and snow accumulation on glaciers**
- **Evaluate and reduce the uncertainty of snow water storage in regional and global water budgets**
- **Validate and improve predictive hydrologic models to reduce uncertainties in water forecasts**
- **Validate the magnitude and dynamics of snow and ice processes in climate models with observations and assess the validity of feedbacks represented in the models.**
- **Improve the representation of snow and ice processes in regional and global climate models to reduce uncertainty in predictions.**
- **Support development of downscaling techniques for snow distribution at climate model grid scales to local-regional scales.**

Secondary Mission Objectives: Snow and Ice Process Studies and Modelling

- Explore the distribution of snow properties in high-latitude regions with focus on the implications for terrestrial carbon cycling and trace gas exchanges
- Evaluate mass balance of a broad sampling of glaciers and ice sheets worldwide to understand current changes and place them into historical context
- Validate and improve lake ice process models with observations of ice properties to reduce model uncertainty and assess effects of lake ice on surface energy exchanges
- Explore the magnitude and distribution of snow on sea ice and thin sea ice to help understand their role for sea ice thermodynamics and mass balance

Observation Requirements

Variable	Spatial Scale (regional, global)	Sampling	Accuracy (rms)
Primary Parameters			
Seasonal Snow Cover			
Water equivalent	200, 500 m	3-15 d	*3 cm for SWE ≤ 30 cm; 10%*
Snow extent	100, 500 m	3-15 d	5% of area at HRU
Glaciers			
Snow accumulation	200, 500 m	15 d	10% of maximum
Secondary Parameters			
Seasonal Snow Cover			
Melting snow area	100, 500 m	3 d	5% of area at HRU
Snow depth	200, 500 m	3-15 d	10% at hillslope scale

Glaciers

Diagenetic facies types; Glacial lakes

Lake and River Ice

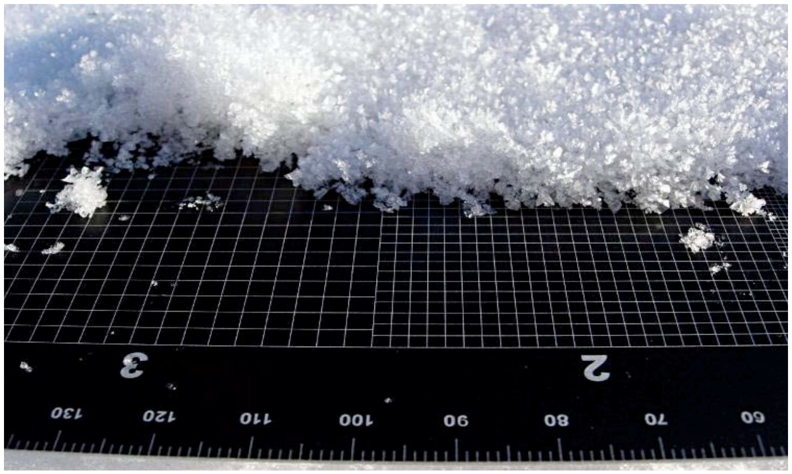
Ice area; Freeze up and Melt onset

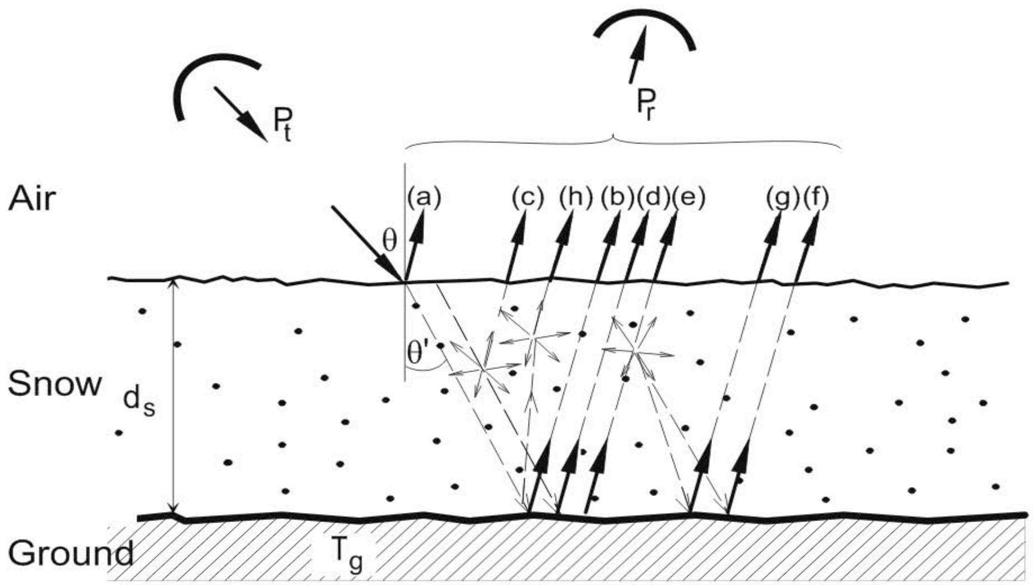
Sea Ice

Type and thickness of thin ice

Snow on sea ice (SWE, snowmelt onset and area)

Backscattering Signal and Physical Parameters





Snow parameters affecting microwave propagation in snow packs:

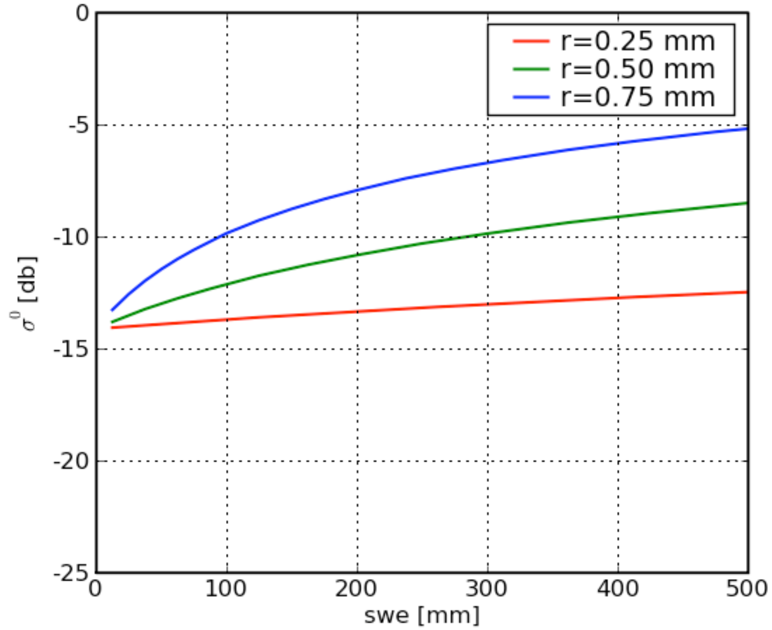
Volume, interaction, and surface backscattering components

Main parameters:
- snow water equivalent, SWE
- grain size
- soil background
- liquid water (if melting)

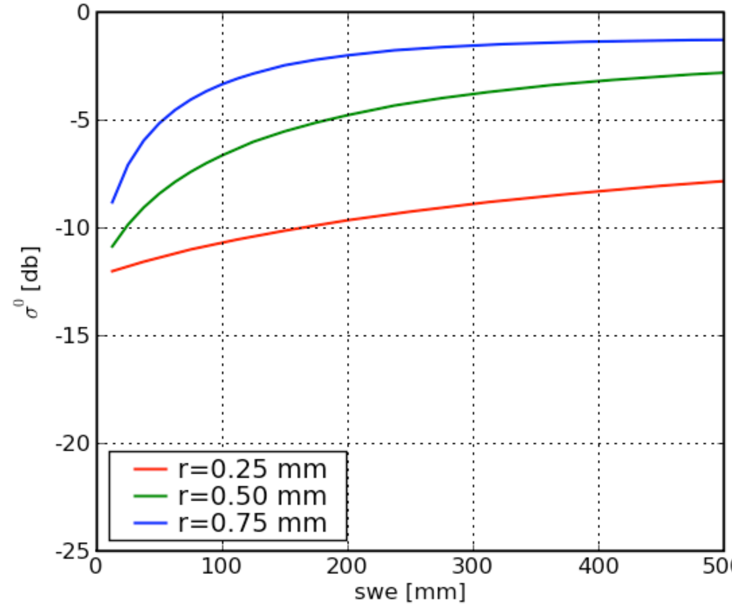
Further parameters:
- snow depth and density (=SWE)
- grain shape
- stratification

SWE Sensitivity to Backscatter

10 GHz VV



17 GHz VV



θ= 30°

Snow density ρ = 250 kg/m^3

Grain shape: Ellipsoids

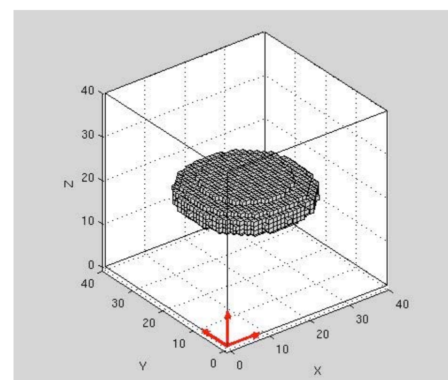
(b/a) = 0.25

Grain equivalent radius

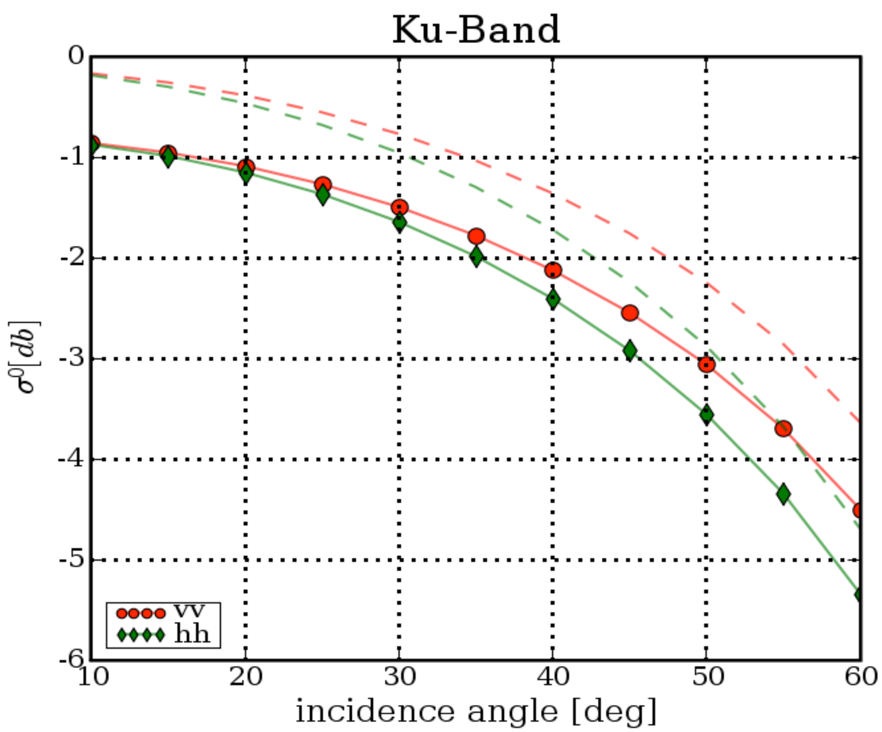
d =0.25, 0.50, 0.75 mm

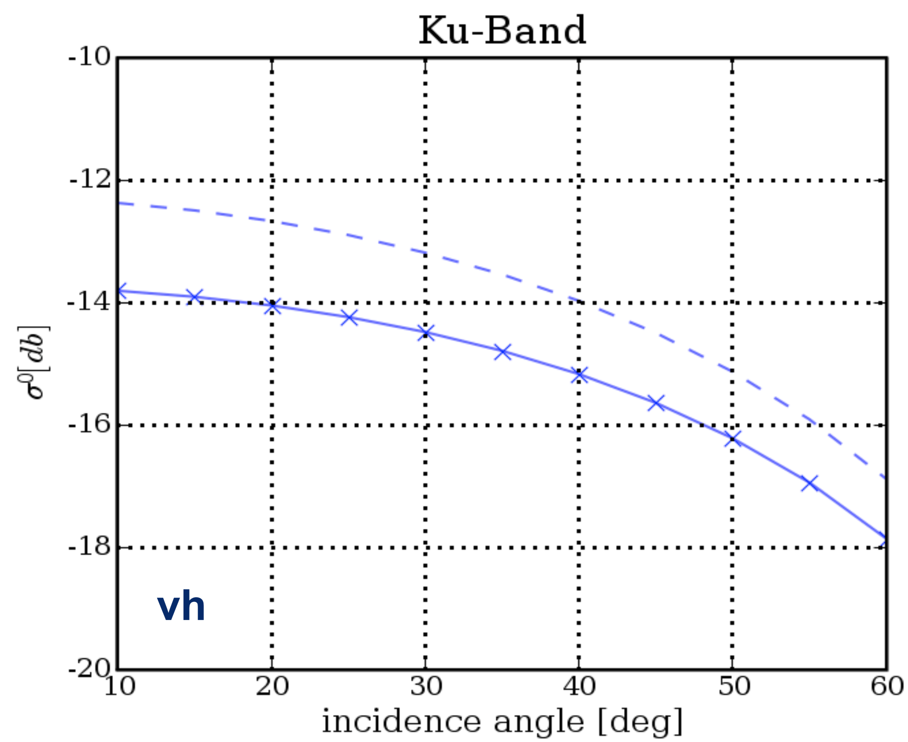
IEM for surface

Radiative transfer model
Grain characterisation by DDA



Snow Accumulation in Percolation Zone of Glaciers Sensitivity Study





Broken Line – Percolation
Full Line – Percolation and winter snow

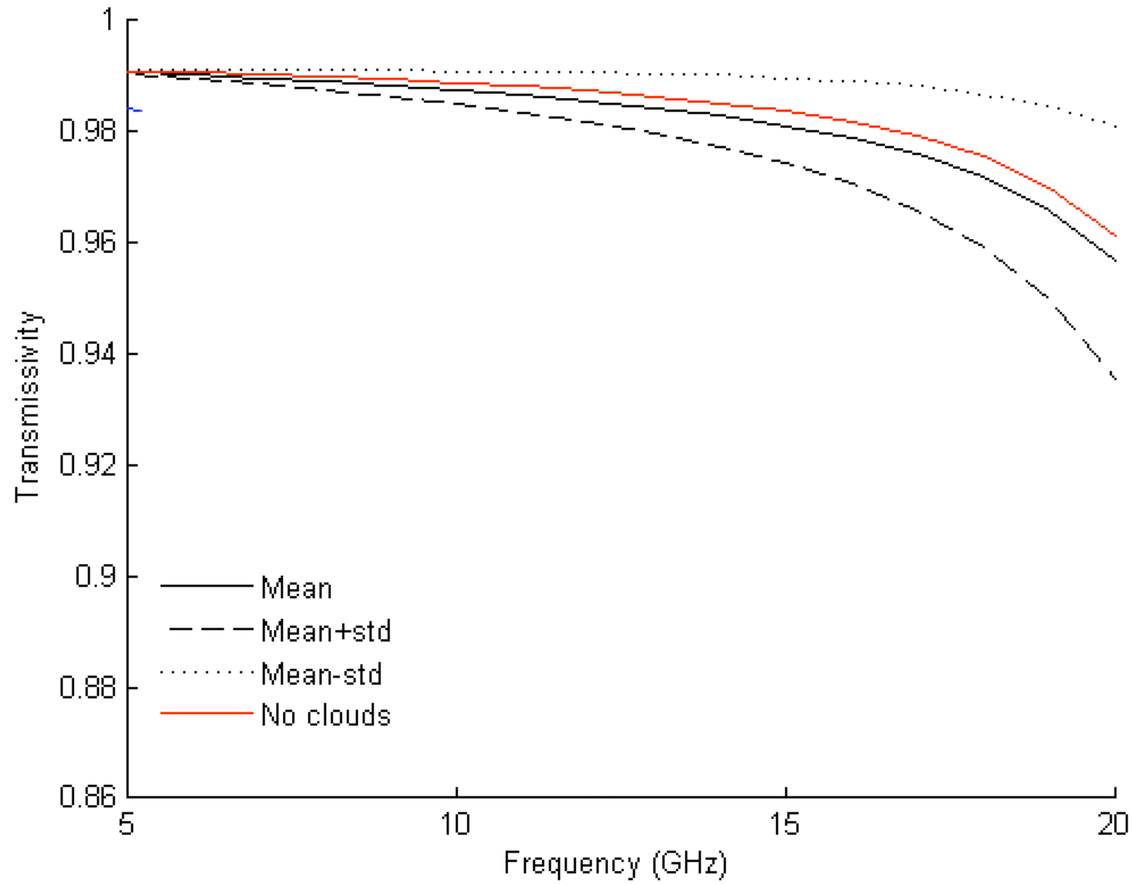
Based on dual layer RT Model by J.C. Shi & J. Du

Winter snow
(Layer 1): Equivalent particle radius r = 0.2 mm
Ellipsoid axis ratio = 0.50
Snow density = 300 kg/m3
Snow depth = 1m

Percolation facies
(Layer 2): Equivalent particle radius r = 2 mm,
Ellipsoid axis ratio = 0.50,
Snow density = 400 kg/m3,
Snow depth semi-infinite

Study of Atmospheric Propagation Effects

Atmospheric transmissivity calculated for statistical atmospheric characteristics from ERA40 data, for Northern Finland, winter conditions



Conclusion:

- Atmospheric corrections based on climatological mean values are suitable for snow retrievals.
- Further option: atmosph. parameters from ECMWF analysis

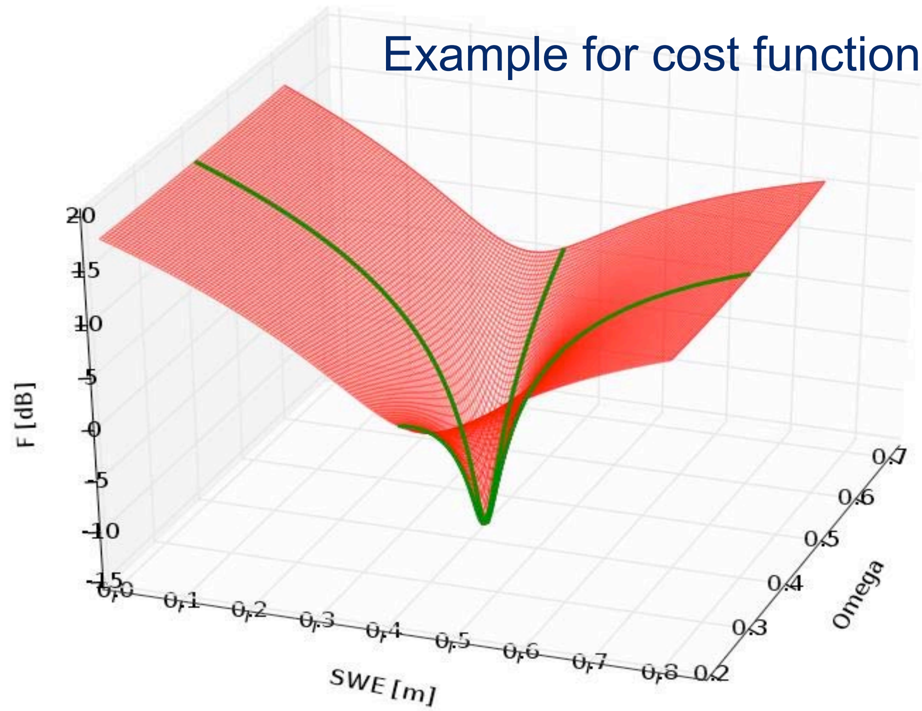
Baseline Version for SWE Retrieval
Optimized Inversion of Physical Model

The baseline algorithm for SWE retrieval applies the optimized statistical inversion technique. It uses a radiative transfer model with reduced number of free parameters and applies the Nelder-Mead optimization algorithm.

$$F = \sum_{i=1}^{n} \frac{1}{2\sigma_i^2} \left[\Phi_i \left(x_1, \ldots., x_q; c_{1i}, c_{2i}, \ldots., c_{ri} \right) - Z_i \right]^2 + \sum_{j=1}^{q} \frac{1}{2\lambda_j^2} \left(x_j - x'_j \right)^2$$

Φ_l Forward RT model
Z_i Backscatter Measurement
σ Measurement noise
x_i State variables (1, …., q)
c_i Configuration parameters
λ_i A priori standard deviation

Example for cost function



Free parameters:
- SWE
- volume scattering albedo (ω)
- co/cross pol ratio

RT Model for Iterative SWE Retrieval

RT model with reduced set of free parameters for iteration

$$\sigma^t_{pq}(\theta_i) = \mathrm{T}^2_{pq}(\theta_t)\left[\frac{\omega_{pq}}{2}\cos(\theta_t)\left\{1-\exp\left(\frac{-2k'_e\,SWE}{\cos\theta_t}\right)\right\} + \sigma^G_{pq}(\theta_t)\exp\left(\frac{-2k'_e\,SWE}{\cos\theta_t}\right)\right]$$

k‘$_e$ – density normalized extinction coefficient

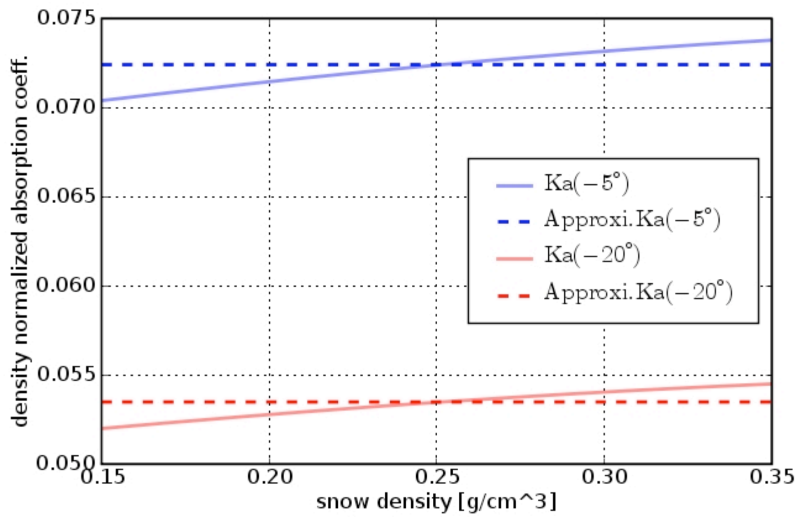
Measurement vector of backscatter :

$$\sigma^t_i = \sum_{i=1}^{4}\frac{\omega_i}{2}\cos\theta_t\left(1-t_i^2\right)+\sigma_i^G t_i^2$$

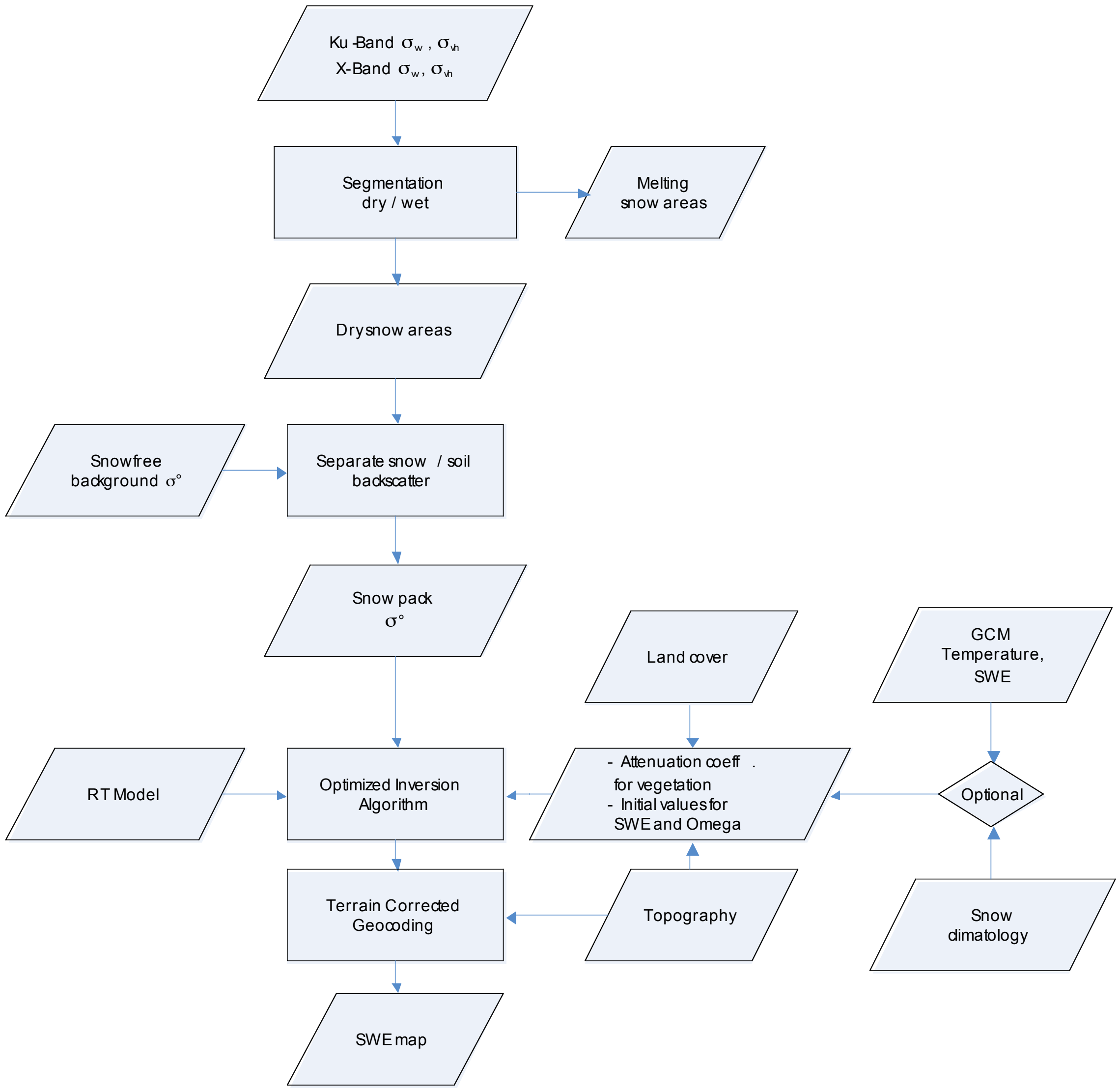
Transmission coefficient

$$t^2_{i;i=1,2,3,4} = \exp\left(-\frac{2\left(\omega_i + k'_{a,i=1,3}\right)SWE}{\cos\theta_t}\right)$$

k‘$_a$ – density normalized absorption coefficient estimated from snow temperature



Processing Line for SWE Retrieval



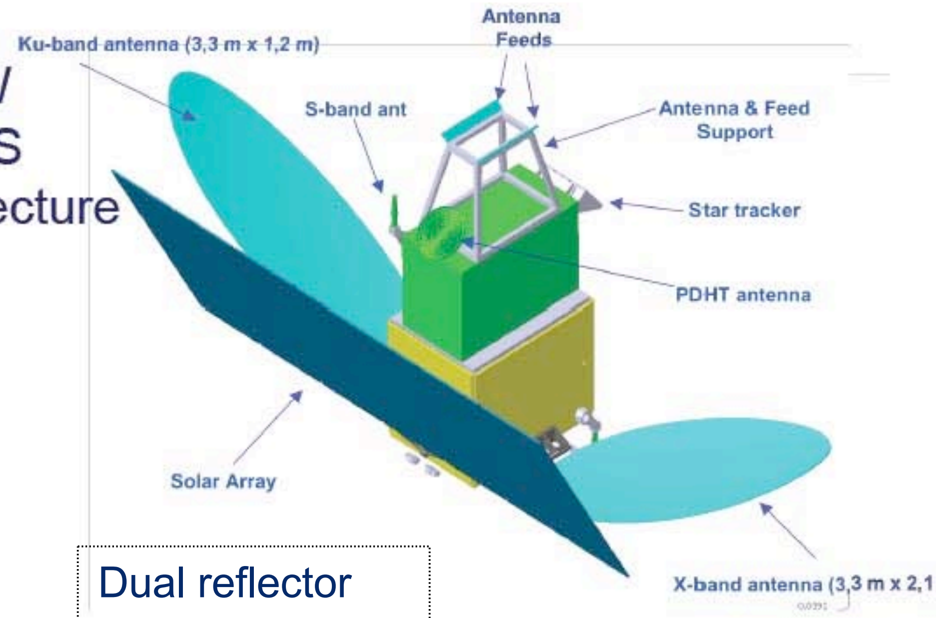
$CoReH_2O$ – Instrument Design Parameters

Parameter	*Ku-band SAR*	*X-band SAR*
Frequency	**17.2 GHz**	**9.6 GHz**
Polarization	**VV, VH**	
Swath width, Inc angle	**≥ 100 km; 30° to 45° range**	
Spatial resolution	**≤ 50 m x 50 m (≥ 5 looks)**	
NESZ	**≤ -20dB VV, ≤ -25dB VH**	**≤ -23dB VV, ≤ -28dB VH**
Radiom. Stability / Bias	**≤ 0.5 dB / ≤ 1.0 dB**	
Antenna concept	**Single or dual reflector with**	**multiple beam feed array**
Peak transmitter power	**1.2 – 1.5 kW**	**1.8 – 2.0 kW**
Nr. of ScanSAR beams	**6**	**6**

Two Proposed Sensor Concepts

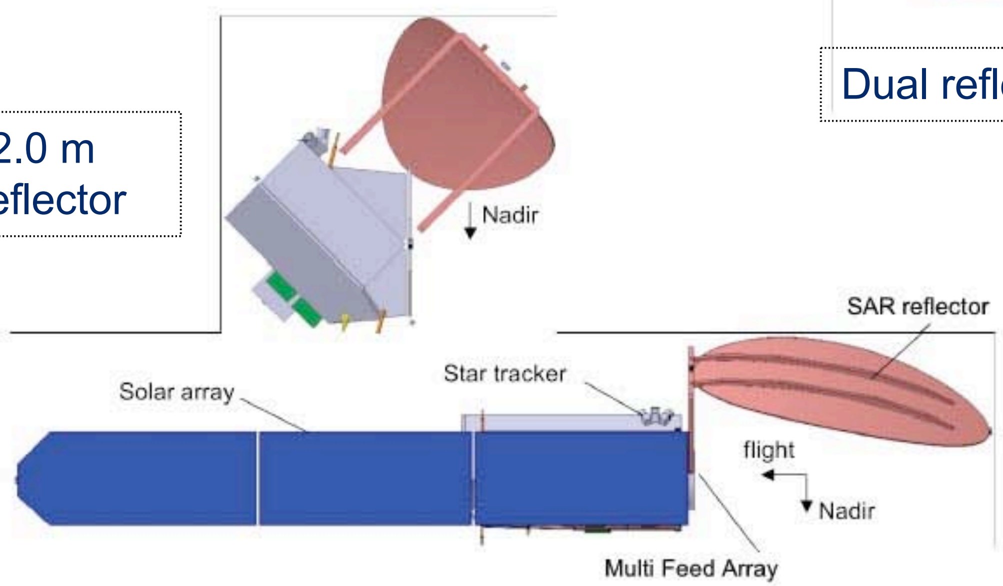
S/C budgets: 1.1-1.3 tons, 3-4 kW
High downlink rate, single/dual GS
High-end X-band downlink architecture
Compatible with VEGA launcher

Results of 2 parallel pre-phase A studies

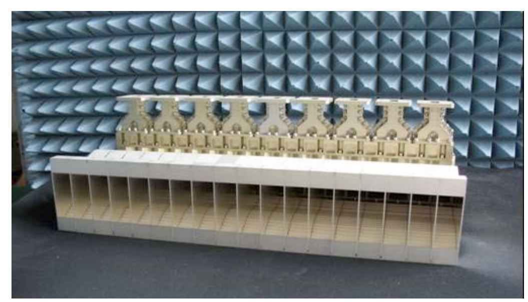


Dual reflector

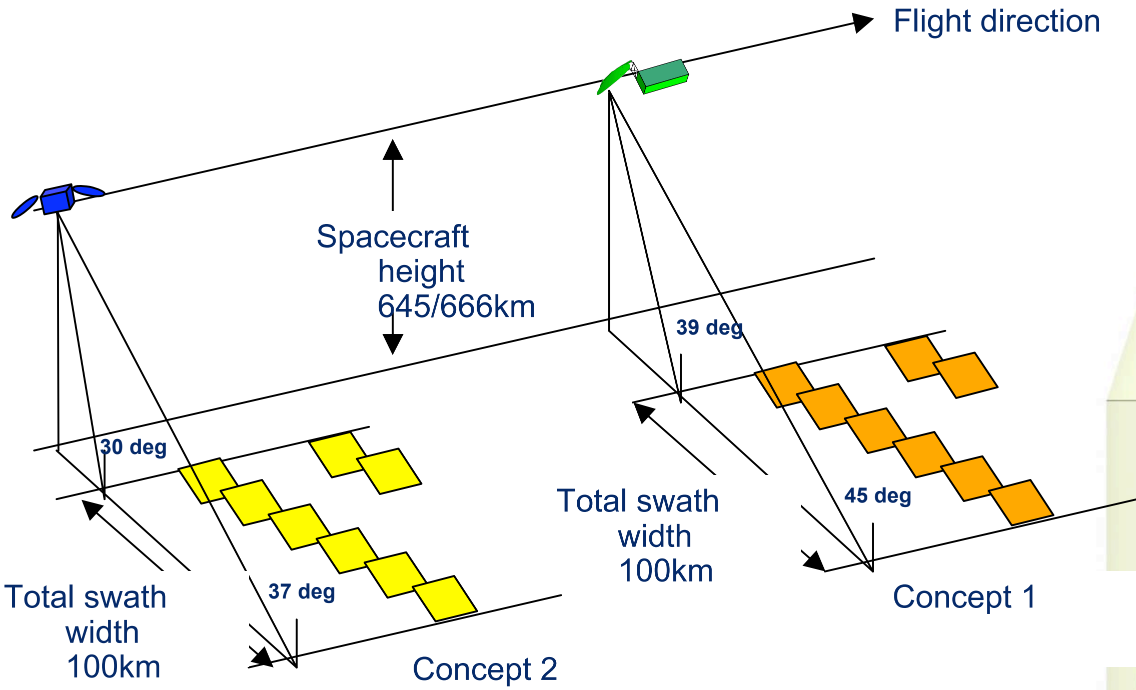
4.5m x 2.0 m
single reflector



Breadboard feed array



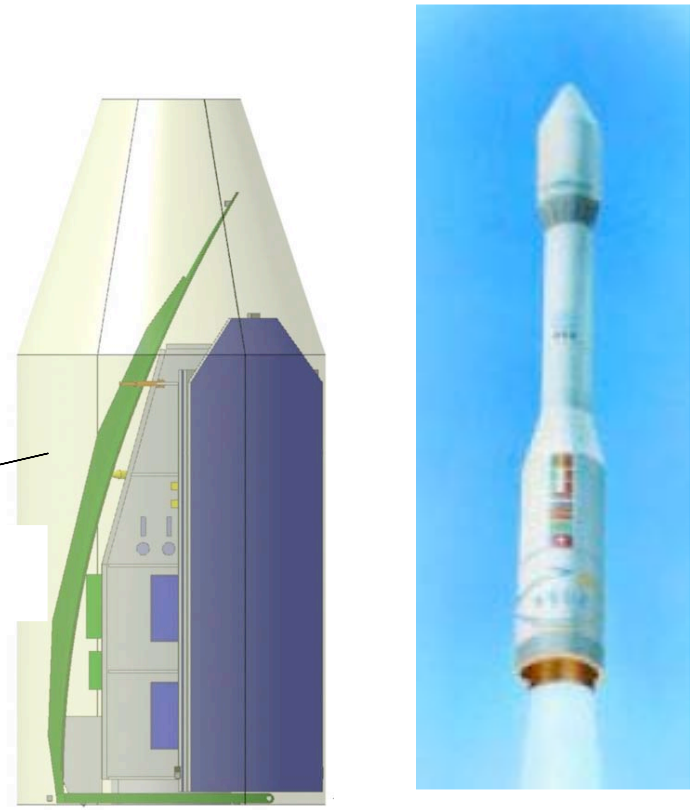
Proposed Technical Solutions



Two mission phases:

•Phase 1 (3d repeat); for model development and validation:

• Phase 2 (15 d repeat): Near global coverage of snow and ice



Accommodation in VEGA launcher

Example for Phase 1 Orbit Coverage

3-day Repeat Orbit:

Motivation -
To cover time scale of forcing by mid-latitude synoptic systems

Objectives

• Improve data assimilation techniques and downscaling for geophysical models (land surface, hydrology, LAM, GCM, …)

• Investigations at specific test sites to advance and validate retrieval and process modeling techniques

Field Experiments for Ku- and X-band Snow Studies

HeliSnow Campaign 2007/08

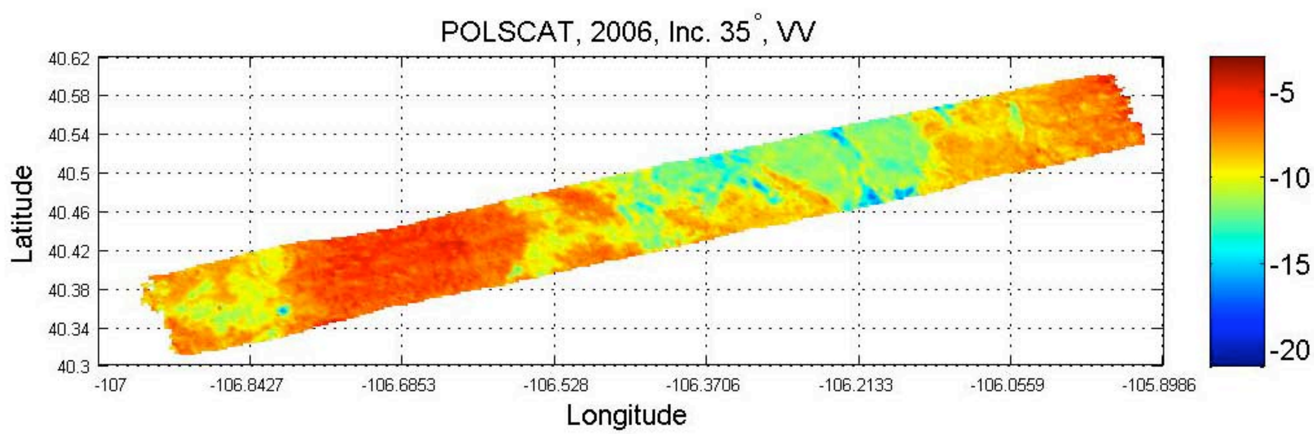
- **ESA-ESTEC**
- **Univ. Hamburg**
- **ENVEO IT**

L-, S-, C-, X-, Ku-Band, co- and cross-pol. measurements at 5 Alpine test sites,

Cold Land Processes Experiments CLPX-II

- **2006-07 Colorado**
- **2007-08 Alaska**

CLPX-II Colorado 2006-07



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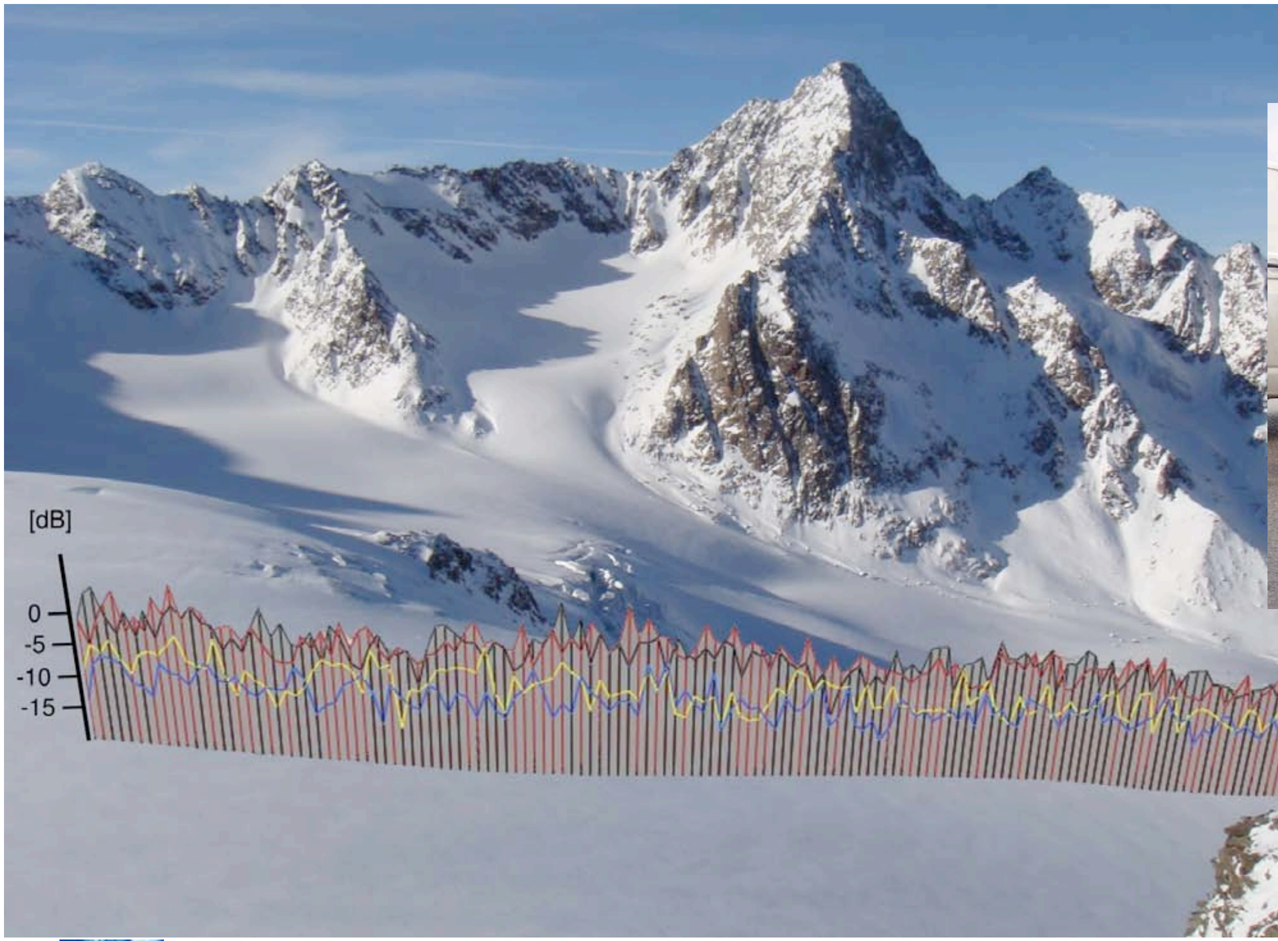
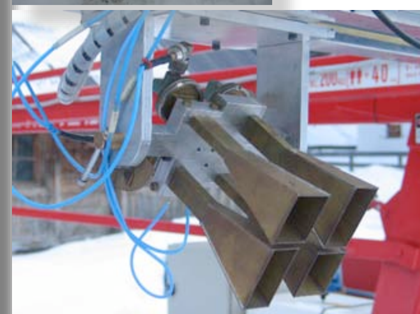
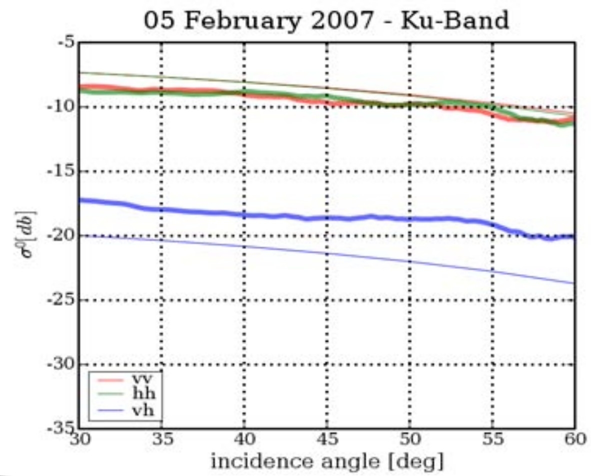


L-, S-, C-, X-, Ku-Band,
co- and cross-pol.
5 Alpine test sites,

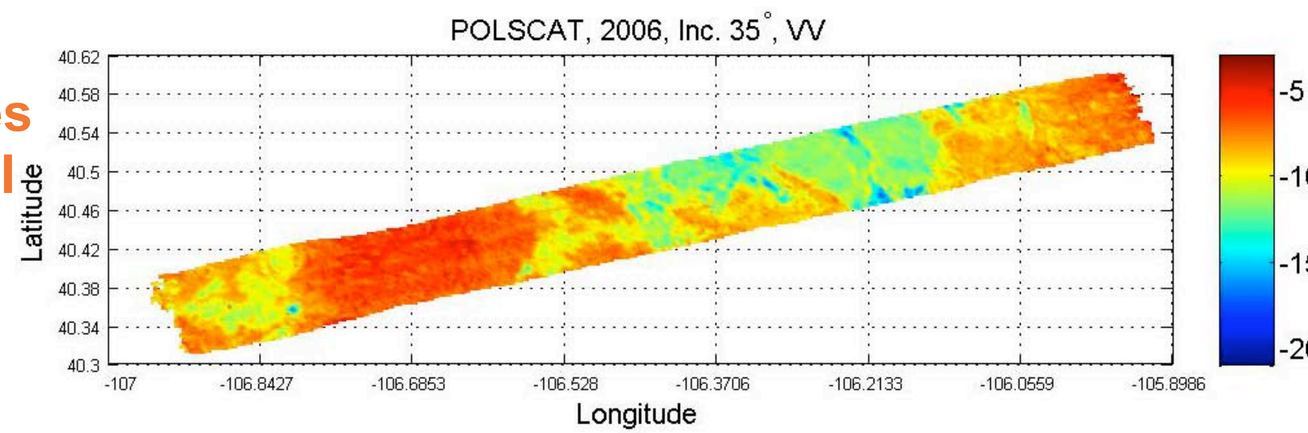
Field Campaigns



SAR Alps 2007



Comparisons – measured and modelled σ°



Cold Land Processes Experiments CLPX-II

- 2006-07 Colorado
- 2007-08 Alaska

Conclusion

- Snow and ice are crucial elements of the water cycle and rapidly changing elements of the global climate system. The 2007 IPCC Report calls for better representation of snow and ice feedbacks in climate models.
- The CoRe-H_2O mission addresses these needs by providing spatially detailed observations of snow mass and other snow properties, to advance the modelling snow cover processes and surface/atmosphere interactions.
- The mission preparations triggered major research activities in experiment an theory of microwave interaction with snow and ice at Ku- and X-band.
- A promising, economical technical solution for the dual frequency SAR is proposed by industry, fully compatible with the mission requirements.

The Next Step:

Earth Explorer User Consultation Meeting:

20 - 21 January 2009

Belém Cultural Centre

Lisbon, Portugal

http://www.congrex.nl/09c01/

ESA consults the Science Community on down selection of Explorer missions for Phase-A studies

Come to the meeting and support CoRe-H_2O !